Nature Returns to Abandoned Industrial Land: Monitoring Succession in Urban-Industrial Woodlands in the German Ruhr

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Introduction

The considerable decline of heavy industry (coal, steel) has led to extensive structural changes in the German Ruhr, leaving behind areas which have been shaped by the profound impacts of industrial use. As long as these industrial abandoned lands are not subjected to use, they experience ecological succession. In 1992, more than 8,000 ha of such land were known in the Ruhr (Tara and Zimmermann 1997). Today the area is estimated to total approximately 10,000 ha.

Depending on the local economic situation, some of these industrial abandoned areas will be used again, for example, as commercial districts, office buildings, housing estates, or as traditional parks. On other sites, however, undirected natural succession continues and produces a mixture of different successional stages that are dominated by short-lived pioneer species, tall herbs, shrubs and trees. On many areas, succession has already led to urban-industrial woodlands which differ in many ways from other types of urban forests (Kowarik 2005). These areas provide considerable potential for developing new green spaces with significant social and ecological functions.

Since 1996, 12 urban-industrial woodlands with a total of 244 ha have been included in the *Projekt Industriewald Ruhrgebiet* (Industrial Forest Project of the Ruhr). This project aims to develop these areas by integrating social and ecological goals (Dettmar 2005). Both cultural remnants and natural processes are found to be highly attractive to local residents (Keil 2005), and the urban-industrial habitats clearly harbour a high number of animal and plant species, including rare species (e.g. Rebele and Dettmar 1996; Gausmann et al. 2004).

Due to the newness of these anthropogenic sites, the way in which ecosystem development will proceed, however, remains an open question.

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This paper reports on a monitoring approach established in 1999 and presents results of the first analysis.

The monitoring approach

The monitoring approach integrates the studies of soil, vegetation and selected animal groups. In total, six permanent plots representing different stages of succession were established. Two plots each were set up at the pioneer, the shrub and the woodland stages.

The heterogeneity within the plots does not allow generalisations regarding succession on industrial abandoned land. Instead, the monitoring aims to document, through examples, the development of and mutual interactions between soil, vegetation and fauna during succession from pioneer to late-successional stages of industrial woodlands. According to the "space-for-time" method, a comparison of plots at different stages of succession will allow tendencies in successional trends to be described (Pickett 1989, Nobis 1998, Purtauf et al. 2004).

The monitoring program is funded by the Ökologie Programm Emscher Lippe (ÖPEL; Ecology Program of Emscher Lippe) and the State Agency for Ecology (LÖBF). The LÖBF co-ordinates the work which is carried out by the University of Essen, the State Agency for Environment, LUA (soil analysis), experts of the LÖBF, the University of Bochum, and independent researchers (on vegetation dynamics, selected animal groups).

Study sites

Three urban-industrial sites were chosen for monitoring the development of soils and the dynamics of plant and animal populations. All study sites are located within the core of the urban-industrial agglomeration of the Ruhr. All were used formerly as coal mines and are now integrated into the Projekt Industriewald Ruhrgebiet, which ensures the future existence of the sites. The first is Zollverein coal mine (20 ha), located within the city of Essen. The other sites are within the city of Gelsenkirchen: the Rheinelbe coal mine (42 ha) and the Alma coal mine (26 ha). The area of each plot is 0.1 ha, including a subplot for vegetation relevées (100 m^2). The other analyses of vegetation structure, soil profiles and faunistic sampling were done outside of this subplot. Table 1 gives further information on the studied plots. For five plots, the parent material for soil genesis was hard coal-mining spoil from a depth of more than 1,000 m; the ecosystem dynamics on the remaining plot started with building rubble.

Table 1. Location of the permanent plots (0.1 ha) on three sites (former Alma, Rheinelbe and Zollverein coal mines). The ecological features describe site and vegetation characteristics at the beginning of the investigation in 1999

Successional stage	Alma (A)	Rheinelbe (R)	Zollverein (Z)
Pioneer stage (P)	Plot PA: recent hard coal-mining spoil with bare ground		Plot PZ: hard coal-mining spoil with sparse vegetation
Shrub stage (S)	Plot SA: rubble with tall herbs and shrubs	Plot SR: hard coal-mining spoil with 5- to 10-year-old birch stand	
Woodland stage (W)		Plot WR: mining spoil dominated by 40- to 50-year-old birch	Plot WZ: mining spoil dominated by 80- to 90-year-old planted black locust

Table 2. Methodological approaches for analysing chemical, physical, microbiological and zoological soil properties in the soil profiles with information on the planned repetitions (repetition intervals in brackets)

Parameters	Method
Chemical (10 years)	
pH value	In 0.01 M $CaCl_2$
Electric conductivity	Electrode in 1:5 soil-to-water suspension
Carbonate content	Volumetric CO_2 measurement with Scheibler-Finkener alkalimeter
Cation exchange capacity (CEC)	Method of Mehlich (Schlichting et al. 1995)
Plant-available phosphate and potassium	By VDLUFA method (Hofmann 1991)
Plant-available magnesium	By calcium-chloride extraction
Content of heavy metals	Aqua regia-extractable contents of Cd, Zn, Pb, Cu, Ni
Pedogenous iron and manganese oxides	Extraction with dithionit (Mehra and Jackson 1960); extraction with NH_4 oxalate according to Tamm/Schwertmann (Schlichting et al. 1995)
Physical (10 years)	
Soil-water content	Gravimetric

Table 2. (cont.)

Bulk density	Gravimetric measurement of 500-cm^3 soil samples
Humus content	Combustion residue loss (gravimetric)
Microbiological (3 years)	
Soil respiration	Oxygen uptake, a Sapromat (Schinner et al. 1993)
Substrate-induced respiration	Oxygen uptake after addition of glucose, Sapromat (Schinner et al. 1993)
Microbial biomass	Indirect estimation by conversion factor from substrate-induced respiration at 22°C (Anderson and Domsch 1978; Alef 1991)
Dehydrogenase activity	With the substrate TTC incubated for 24 h; modified from Thalmann (Schinner et al. 1993)
Cellulose degradation	Litterbag method (Bocock and Gilbert 1957; Dunger and Fiedler 1989; Alef 1991)
Zoological (5 years)	
Lumbricidae: species richness and abundance	formalin expulsion/hand picking
Enchytraeidae: species richness and abundance	Wet extraction according (Dunger and Fiedler 1989)
Springtails (Collembola): determination to genus level and abundance	Dry extraction by Berlese-Tullgren method

Methods

The methods for analysing chemical, physical, microbiological and zoological soil properties are summarised in Table 2. At each permanent plot, a soil profile is dug and analysed according to Hoffmann (1991). Soil types are characterised following the standardised methods (AG Boden 1994, AG Stadtböden 1997). Microbiological parameters are analysed in mixed soil samples.

Vegetation is sampled in 10x10 m^2 plots. Each has four subplots of 1x1 m^2. Cover of plant species is estimated in absolute percentages. In the subplots, individuals of all plant species are counted. Special funnel traps were designed for capturing the diaspore rain (Fig. 1). They are emptied every two weeks. The diaspore bank of the top soil layer is sampled at depths of 0–2, 2–5 and 5–10 cm using a metal cylinder (500 cm^3). Half of the material is studied using the “seed washing by sieve” method, the other half using the “seed emergence” method according to Fischer (1987). For the latter, diaspores are sown on a sterilised soil matrix and observed for a four-week period.

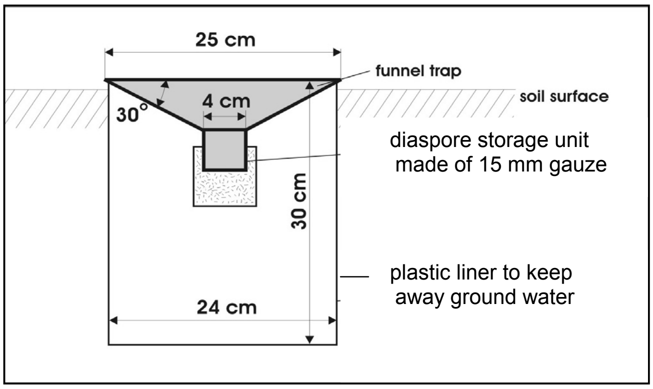

Fig. 1. Construction of the diaspore trap (after Haeupler et al. 2003)

On each permanent plot, the locations of all trees are established to create structure maps of the stand (Leder and Leonhardt 2003). Additionally, the height of the trees, their diameter at breast height (dbh) and their social positions are recorded, using the classification method of Kraft (1884). This classification describes the rank of a tree in comparison to its neighbours by recording the form of its crown. The classes are: (1) superior, (2) dominant, (3) co-dominant, (4) intermediate, and (5) overtopped. For the demographic analysis, saplings with a height of more than 1 m are considered.

By digging up the roots, information about mycorrhiza and root growth is obtained. The analysis will be completed by documenting historical development, and by analysing annual rings and aerial photographs.

The permanent plots are sampled for wild bees, sphecids, hoverflies (syrphids), ants and ground beetles. These groups are chosen because of their suitability as bio-indicators. The ecological requirements of the groups are well known, their lifestyles are adapted to all studied successional stages, with differing habitat requirements within each group. They can be assigned to different trophic levels and use more than one habitat type or habitat structure during their life cycle.

In this paper, only ground beetles and ants are considered. For sampling ground beetles, pitfall traps are used (6 traps per plot; standing time 3x3 weeks per year). In addition, some beetles are caught manually at random. Ant nests are mapped in two 50 m² partial areas per sample plot. The ant studies are completed by manual catches within the total sample plot, in pitfall traps used for ground-beetle mapping, using litter-layer sieving in woodland plots, net catches within higher vegetation and manual catches at random. Due to annual fluctuations in populations, samplings of two consecutive years are evaluated as one investigation unit with a regular repeti-

tion every five years. The initial recording was carried out in 2000/2001. An additional investigation was carried out in 2003.

Results

Soil genesis and chemical characteristics

Hard coal-mining spoil forms the parent material for soil genesis on five permanent plots. Differences among these sites are mainly due to varying gravel and stone (skeleton) contents. With its strong compacted layers of brick debris and a mixture of building rubble, the plot SA differs greatly from all others.

The soil classified as “skeleton-humus soil” on the pioneer sites PA and PZ consists of coarse mining spoil over loess with initial humus accumulation in cavities. A humus topsoil has not developed yet. Mining spoil of younger fills is often compacted. Shallow stagnic soils develop which have temporary wet topsoils. This is a characteristic feature of site PA.

On the shrub sites, a Syrosem-Pararendzina from building rubble over loess was found at site SA and a Syrosem-Regosol from hard coal-mining spoil over loess was found at site SR. “Syrosem” indicates an incipient soil development of raw soils. Due to the rapid soil development by humus accumulation in the humid climate, the soils are already in transition stages to Pararendzina and Regosol from material containing or lacking carbonates respectively. Different thicknesses of the humus horizons (Ah) have been recorded for the two areas.

The two woodland locations show Syrosem and Regosol of hard coal-mining spoil over loess (WR) or a Regosol of hard coal-mining spoil over loess (WZ). The two sites differ mainly in their stage of soil development. The soil development has not yet proceeded on WR due to erosion on its steep slopes. The development of a humus topsoil has been greatly hindered by this. Only small areas of vegetation provide for local soil accumulation and therefore conditions for humus formation. The site WZ, in contrast, is located in a flat area and 20-cm-thick organic layers (L, Of, Oh) and topsoil horizons (Ah) have developed in places. Thick, raw humus layers indicate an acid soil. Old fills of hard coal-mining spoil, in contrast to the younger ones, are usually loosely packed. Site WZ provides a good example of uncompacted soils developing from hard coal-mining spoil.

The investigated soils are at the beginning of their development. They are very gravelly and stony (skeletic). Down to a depth of more than 1 m, the parent material frequently consists of more than 80% skeleton. Therefore the initial stages of soil development on hard coal-mining spoil

strongly restrict root growth. Weathering of skeleton to fine-earth particles is in an initial stage. Therefore the fine-earth content is low. Fine earth supplies plants with nutrients and water. Due to the limited fine earth content only small amounts of nutrients and water can be stored and are, therefore, less available for plants. The nutrient status must be classified as poor with regard to magnesium, phosphate and potassium, except for site WZ. The low fine-earth content also reduces the cation exchange capacity, which is usually very low. The pH values (Fig. 2) on old hard coal-mining spoil are mostly very low (less than pH 4.0; Burghardt 1989). Hard coal-mining spoil that is only a few years old and building rubble material, however, have a moderate alkaline pH value of 7.1–9.0.

Salt washouts can be traced in the decline of electrical conductivity of the soil-water suspension after 1 year at site PA. In 1999, we measured approximately 290–330 µS/cm in the upper 10 cm layer; 1 year later the electrical conductivity dropped to approximately 250–260 µS/cm. This is the "advance notice" of acidification, which usually starts immediately after the washout of the salts.

The heavy-metal concentrations of the fine-earth fraction are mostly slightly elevated. In the raw humus layer at site WZ, 116 mg of copper per kg were measured. Levels of zinc above 150 mg/kg can often be measured in the topsoil. Lead content frequently lies between 76 and 552 mg/kg in the fine-earth material. Nickel and cadmium, however, do not show elevated results. It is striking that plant-available and water-soluble (ammonium-nitrate extract) lead occurs at slightly elevated levels of more than 0.1 mg/kg.

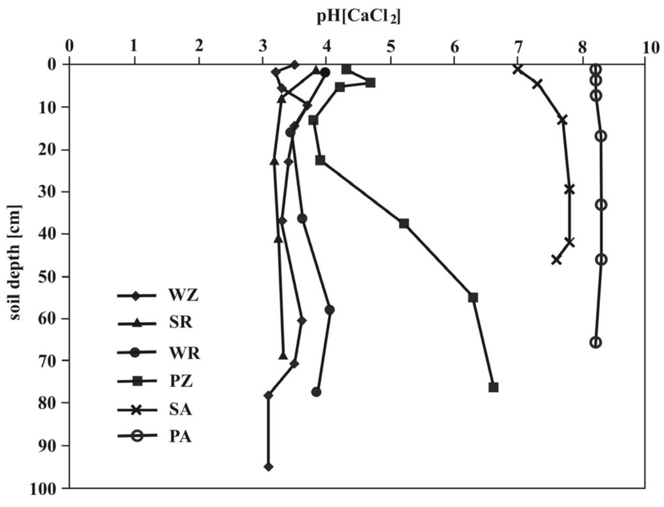

Fig. 2. Depth profiles of the pH values at the sampled plots (for abbreviations see Table 1; after Burghardt et al. 2003)

Soil fauna and microbiological activity

Few organisms of the macro- and mesofauna live in the raw soils. The pioneer sites are still free of earthworms. Generally, no microbiological activity was found on these sites (average soil respiration: 0.04 mg O_2/100 g dry matter/h). In the shrub and woodland sites, the level of microbiological activity ranged between mean moderate and high (average soil respiration from 0.1–1.2 mg O_2/100 g TS/h). Due to ongoing acidification, a reduction in microbiotic activity is to be expected. This would enhance fungi instead of bacteria and would subsequently decrease the decomposition rate of litter.

In the shrub site SR and woodland site WZ, the population density of lumbricids is still low with 6–12 individuals per square meter (Fig. 3). The lack of litter consumers, particularly big, deep-digging earthworms, leads to a "decomposition jam" and an accumulation of litter and thick raw humus forms. Such raw humus forms are typical of the acidic, low-nutrient soils that are found at the site WZ. The lumbricid presence at WR is completely different. Here, big, deep-digging earthworms occur abundantly throughout the mineral soil although they live under the same acidic conditions as the previous cases (pH_{CaCl2}<4). In contrast to the lumbricids, the enchytraeids indicate a future change in the composition of the soil macrofauna in response to acidic soil conditions. The dominant species *Cognettia sphagnetorum* and *Marionina clavata* are typical micro-annelids of acidic top layers.

At the rubble site SA, the number of lumbricids is typical of moderately alkaline pH values. Surprisingly, there is a clear dominance of animals that usually live in humus layers over those living in mineral-soil layers, although we recorded no significant humus layer at this site.

Dynamics of diaspore banks

The diaspore bank has been analysed at both shrub sites. In three years of investigation, 58 plant taxa were found in the diaspore bank at the rubble site SA (see Appendix, Table A1). The above-ground vegetation of this site is dominated by tall herbaceous perennial plants such as *Solidago gigantea* and some woody species such as *Salix alba* and *Populus alba* with a total of 48 species recorded in the 10x10 m² plot. The results illustrate the changes in the diaspore banks. However, fluctuations in the occurring taxa also depend partly on the chosen study method. Not all taxa found during seed washing left viable seeds (e.g. *Centaurium pulchellum,*

Chenopodium rubrum), and applying the seed-emergence method revealed a group of additional taxa (e.g. *Echium vulgare, Festuca rubra* agg.).

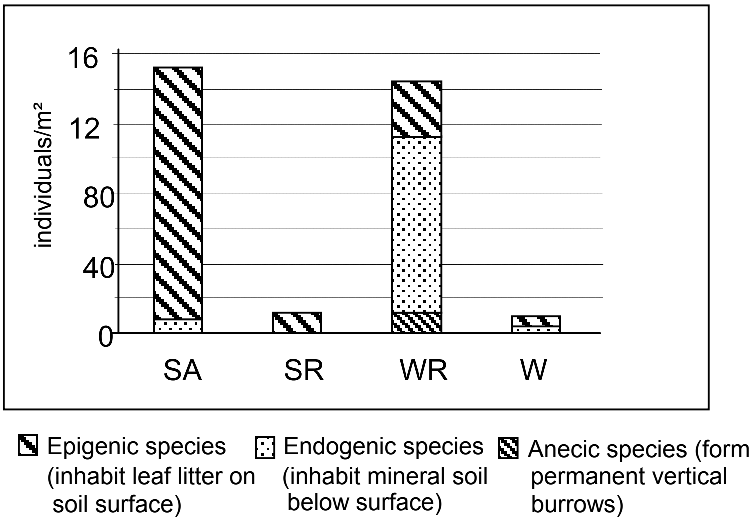

Fig. 3. Abundance and relative proportion of life forms of the lumbricids at the sampled plots. Only shrub and woodland sites are shown, because the pioneer sites were free of lumbricids (for abbreviations see Table 1)

The changes in the diaspore bank diminish further with the progression of ecological succession. Therefore, not only is the number of taxa in the woodland plots low, but the variation in the woodland taxa over the years is extremely low as well.

The other shrub site, SR, is already dominated by pioneer trees (*Salix caprea, Betula pendula*). Similar to the previous site, birch is the most common species in the diaspore bank, due to a high propagule pressure at both sites. However, at SR, only 25 taxa were found in the diaspore bank (Appendix, Table A2).

Demographic structure of woodland stages

The demographic structure of the populations of woody plants was analysed at both woodland sites (Table 3). The site WR is an approximately 40-year-old stand that is still dominated by European birch (*Betula pendula*) as a pioneer species. Some late-successional species indicate the future direction of succession. Most common is the shade-tolerant sycamore

maple (*Acer pseudoplatanus*) which is already established under the canopy of birch (Fig. 4). Other tree species occur in the herb layer (*Acer campestre, A. platanoides*, *Carpinus betulus*, *Crataegus* x *macrocarpa*, *Prunus serotina*, *Quercus robur*). In the herb layer, typical early-successional species are still present (*Agrostis stolonifera*, *Cerastium holosteoides*, *Epilobium ciliatum*), but woodland species indicate the further development of the stand (*Dryopteris filix-mas*, *D. carthusiana*, *Deschampsia flexuosa*). The moss *Mnium hornum* is indicative of the strongly acidic soil conditions.

At the second woodland plot (WZ), the North American black locust (*Robinia pseudoacacia*) had been used for recultivation purposes. Within the 80- to 90-year-old stand, a strong natural dynamic is apparent. The black locust is still dominant, but no increase in height occurs in diameter classes above 30 cm (Fig. 5). Instead, some trees are already beginning to die. Gap formation enhances the regeneration of both black locust and other trees. Black locust still predominates in the shrub layer. Due to the poor decomposition of its litter, a thick raw humus layer has accumulated. The herb layer mainly consists of *Rubus* spp. (*R. elegantispinosus, R. nemorosoides*) and fern species (*Dryopteris dilatata, Athyrium filix-femina*).

Table 3. Demographic analysis of urban-industrial woodlands. *Site WR* 40-year-old stand dominated by birch, *site WZ* 80-year-old stand dominated by *Robinia*. Only saplings with a height of more than 1 m are considered. *K 1* refers to the Kraft classification "superior" trees, *K > 4* to "overtopped" trees, *asterisks* indicate data that were not analysed

	Saplings / trees per hectare		Diameter at breast height (cm)			Height (m)			K 1 (%)	K<4 (%)
	n	%	mean	max	min	mean	max	min		
Site WR										
Betula pendula	2610	60	9.6	21.8	0.9	10.1	17.5	1.5	28	14
Sambucus nigra	960	22	3.7	8.4	2.0	3.6	3.7	3.6	*	49
Acer pseudo-platanus	620	14	3.9	16.7	0.4	3.6	9.3	1.4	2	16
Prunus padus	30	1	3.8	4.9	3.1	*	*	*	*	*
Fraxinus excelsior	30	1	2.8	3.3	2.3	*	*	*	*	*
Salix caprea	30	1	19.1	27.0	6.3	*	*	*	67	33
Salix cinerea	30	1	10.1	12.7	7.4	8.2	11.5	6.1	*	33

Table 3. (cont.)

Site WZ										
Robinia pseudoacacia	840	77	21.9	52.5	2.2	7.9	21.5	1.3	6	64
Sambucus nigra	220	20	4.2	7.8	2.1	3.2	4.5	1.0	0	100
Acer pseudo-platanus	30	3	3.4	4.7	2.6	*	*	*	0	100

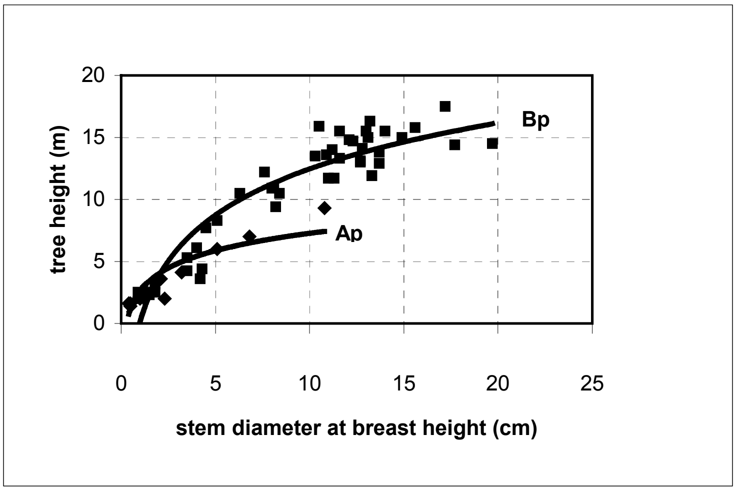

Fig. 4. Height versus diameter at breast height of *Betula pendula* (Bp) and *Acer pseudoplatanus* (Ap) in a 40-year-old birch stand at site WR

Ants and ground beetles

Do typical woodland fauna emerge in isolated urban-industrial woodlands? This question is addressed here using ants and ground beetles as indicator groups. The species composition in both groups shows significant differences between the pioneer, shrub and woodland sites (Figs. 6, 7). Generalists and species of dry, warm and open habitats dominate in the early stages. They are still present in the woodlands, but here, typical woodland species begin to dominate.

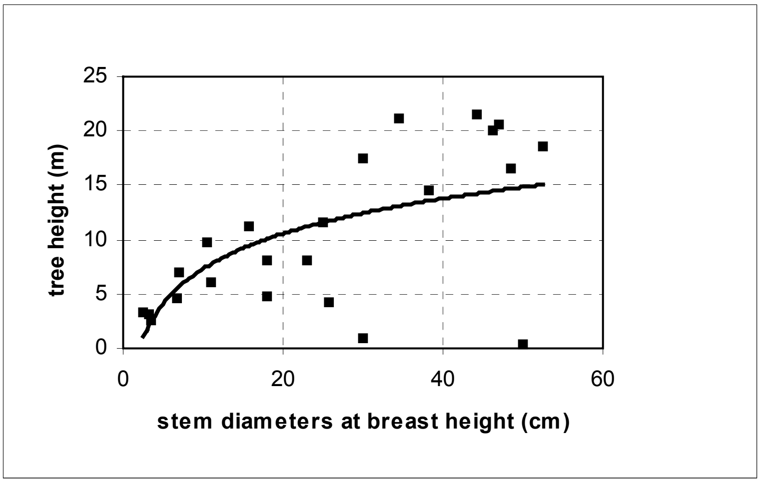

Fig. 5. Height versus diameter at breast height of *Robinia pseudoacacia* in an 80- to 90-year-old black locust stand at site WZ

There are obvious differences in the species richness of the two woodland sites. At the birch site WR, 14 ant species were found (12 with evidence of nests), at the black locust site WZ only 6 (5 with evidence of nests). Common species that are typical of the top layer of litter, such as *Stenamma debile*, are missing. Only three species of ground beetles were recorded at WZ over the three years of investigation. Two of these are typical woodland species that are capable of flying (see Table 4), the third is a xerophile species typical of open habitat conditions (*Harpalus rubripes*), and represents by far the most individuals. At the birch site WR, 11 ground beetle species have been recorded. Seven of these prefer woodlands, and they make up the majority of the individuals.

The differences between the two woodland sites may be due to the fact that site WZ is more isolated than site WR from old parks and remnants of the traditional open landscape. At WR, two of the woodland species are unable to fly (*Carabus nemoralis, C. coriaceus*), which results in reduced opportunities to colonise isolated habitats. In contrast, the two woodland species found at WZ were small and able to fly (Table 4). For ants, however, isolation is of less importance, because sexually mature individuals can fly. The low species richness at site WZ may be due to the low occurrence of greenflies (aphids) in the *Robinia* stands. Here, this important food resource of ants is confined to *Sambucus nigra* and *Acer pseudoplatanus*.

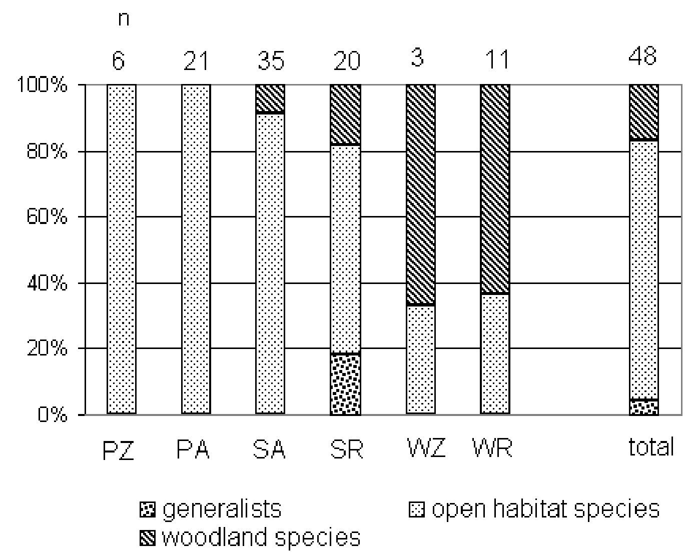

Fig. 6. Proportion of different ecological groups of ant species in pioneer, shrub and woodland plots (for abbreviations see Table 1). The results are the summary of data for 2000, 2001 and 2003; *n* indicates the total number of species

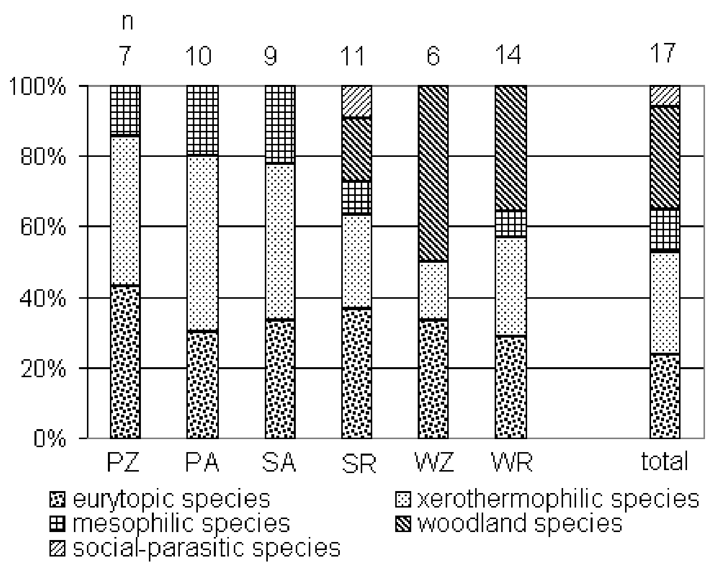

Fig. 7. Proportion of different ecological groups of ground beetle species in pioneer, shrub and woodland plots (for abbreviations see Table 1). The results are the summary of data for 2000, 2001 and 2003; *n* indicates the total number of species

Conclusions

Hard coal-mining spoil as soil parent material leads to extreme habitat conditions. The soils are very gravelly, stony and poor in fine earth and nutrients. Except on sites with fresh depositions of spoil, pH values are very low, which frequently increases the availability of heavy metals. This leads to slow migration of soil fauna and to slow decomposition of litter and soil development. Under these conditions, new types of plant communities arise on the post-industrial sites. The pioneer communities are usually rich in species that originate from a broad array of habitats (ruderal and salty habitats, river banks, arable fields, grasslands) or that were introduced from other regions. The comparison of different-aged sites shows that species richness will decline during succession. This also holds true for endangered early-successional species (Rebele and Dettmar 1996, Weiss and Schütz 1997, Weiss 2003b)

On the other hand, woodland species, both plants and animals, begin to colonise young woodland sites that are still dominated by pioneer trees such as birch and black locust. Examples include tree species (*Quercus robur, Acer pseudoplatanus, Carpinus betulus*), fern species (*Athyrium filix-femina, Dryopteris filix-mas, D. carthusiana*), and ground beetles (*Carabus nemoralis, C. coriaceus*). Differences between the plots may be attributed to isolation effects and to different food resources in stands of native (birch) versus non-native (black locust) tree species. In both woodland plots, early- and late-successional plant and animal species occurred together. This may be due to the immaturity of the woodlands and to their close connection to open habitats which is characteristic of urban-industrial woodlands. Similar results have been found when comparing the different succession stages of a derelict railway area in Berlin (Platen and Kowarik 1995). Further research will reveal whether the co-existence of different species groups remains a feature of the studied woodland communities.

A second open question is that of the direction of woodland succession. Late-successional tree species such as *Acer pseudoplatanus* or *Quercus robur* are already established under the canopy of birch- and black locust-dominated stands. It is doubtful, however, that these species will quickly outcompete the pioneer tree species. Obviously, the extreme soil conditions of the hard coal-mining spoils will remain unchanged for a long time. This may reduce the growth and competitiveness of species such as *Acer pseudoplatanus.* In the black locust stand, some of the taller trees have begun to die. This enhances the establishment of other tree species, but vege-

Table 4. Occurrence of ground beetles (carabids) on permanent plots in pioneer, shrub and woodland sites (0.1 ha; for abbreviations see Table 1). Data are the results of sampling by ground traps in 2000, 2001 and 2003. Column 2 (*W*, type of wings) gives information on species' dispersion ability: *b* brachypterous (unable to fly), *m* macropterous (able to fly), *d* dimorphous (both types occur)

	W	Pioneer sites						Shrub sites						Woodland sites					
		PZ			PA			SA			SR			WZ			WR		
		00	01	03	00	01	03	00	01	03	00	01	03	00	01	03	00	01	03
Total species richness		6	4	1	7	11	15	23	23	14	12	10	5	3	3	3	6	6	8
Total number of individuals		52	7	10	59	39	112	148	132	100	39	52	22	247	149	162	77	43	61
Woodland species richness		0	0	0	0	0	0	0	2	2	6	5	3	2	2	2	3	4	6
Total number of individuals		0	0	0	0	0	0	0	2	2	30	46	20	52	26	20	73	41	59
Carabus coriaceus	b	-	-	-	-	-	-	-	1	1	1	1	-	-	-	-	-	-	2
Carabus nemoralis	b	-	-	-	-	-	-	-	-	1	-	1	7	-	-	-	35	21	40
Leistus rufomarginatus	m	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1
Nebria brevicollis	m	-	-	-	-	-	-	-	1	-	2	1	4	-	-	-	-	-	1
Notiophilus rufipes	d	-	-	-	-	-	-	-	-	-	2	3	-	4	3	14	13	5	2
Notiophilus biguttatus	d	-	-	-	-	-	-	-	-	-	23	40	9	48	23	6	25	14	13
Pterostichus strenuus	d	-	-	-	-	-	-	-	-	-	1	-	-	-	-	-	-	-	-
Pterostichus oblongopunctatus	m	-	-	-	-	-	-	-	-	-	1	-	-	-	-	-	-	1	-

tative regeneration of black locust also occurs in such stands and may prolong the predominance of the North American species (Kowarik 1996).

In addition to natural processes, the undirected succession of industrial abandoned land will be differentiated by the recreational activities of local people who make use of these new types of woodlands (Keil 2005). The quality of these sites is mostly due of the diverging patterns of pioneer, shrub and woodland stages and to the remnants of the industrial history. Thus, concepts for developing this post-industrial landscape should combine approaches that both enhance wilderness and maintain open habitats and cultural remnants. This is the main idea of the Projekt Industriewald Ruhrgebiet, which aims to enhance the social and ecological functions of the urban-industrial woodlands (Weiss 2003b, Dettmar 2005).

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Appendix

Table A1. Diaspores in the diaspore bank of shrub site SA on industrial land (rubble). *W* Results of seed washing method, *E* results of seed emergence method, *asterisks* indicate species which are common in the above-ground vegetation

Year of investigation	2000				2001				2003			
Date of collection	14 Jul		2 Oct		9 May		10 Sept		22 Jul		20 Sept	
Species / method	W	E	W	E	W	E	W	E	W	E	W	E
Achillea millefolium agg.*	-	-	-	-	-	-	-	-	-	-	1	8
Agrostis sp.	-	-	-	95	-	-	-	-	-	-	-	-
*Agrostis stolonifera**	-	2	-	-	-	-	5	-	-	-	-	-
*Anagallis arvensis**	-	-	1	1	-	-	-	-	-	-	1	1
Arenaria serpyllifolia	-	2	-	-	-	-	-	-	-	2	-	-
*Artemisia vulgaris**	-	-	-	-	-	-	1	-	-	-	-	-
Atriplex prostrata	-	-	-	-	-	-	1	-	-	-	-	-
*Betula pendula**	-	-	13	-	165	-	107	2	8	2	89	23
*Buddleja davidii**	-	-	-	-	-	-	-	-	-	-	2	-
Calystegia sepium	-	-	-	-	-	-	-	2	-	-	-	-
Cardamine hirsuta	-	1	-	-	-	-	-	1	-	-	-	-
Centaurium erythraea	-	-	-	-	-	-	5	3	-	-	-	-
*Centaurium pulchellum**	-	-	-	-	-	-	43	-	-	-	2	-
*Cerastium holosteoides**	-	-	-	-	-	-	-	-	-	-	1	-
Chenopodium glaucum	-	-	-	-	-	-	-	1	-	-	-	-
Chenopodium rubrum	-	-	-	-	-	-	37	-	-	-	-	-
*Cirsium arvense**	-	-	-	-	-	-	1	-	-	-	-	-
Conyza canadensis	-	-	-	-	-	-	-	-	-	-	1	1
*Daucus carota**	-	-	20	-	-	2	1	4	-	-	-	4
Echium vulgare	-	-	-	-	-	-	-	-	-	2	-	3
Epilobium ciliatum	-	-	-	1	-	-	-	-	-	-	-	-
*Epilobium hirsutum**	-	-	-	-	-	-	1	-	-	-	-	-
*Epilobium parviflorum**	-	-	-	-	-	-	1	-	-	-	-	-

Table A1. (cont.)

Epilobium spec.	-	-	-	-	-	-	-	5	-	-	-	-
Epilobium tetragonum	-	-	-	-	-	-	1	-	-	-	-	-
*Eupatorium cannabinum**	-	-	-	-	-	-	2	-	-	-	-	-
*Festuca rubra agg.**	-	-	-	-	-	-	-	-	-	3	-	2
Fragaria vesca	-	-	-	-	-	-	2	-	-	-	-	-
Galinsoga ciliata	-	-	-	-	-	-	-	2	-	-	-	-
Geranium molle	-	-	-	-	-	-	-	-	-	2	-	1
Hieracium sp.	-	1	1	-	-	-	-	-	-	-	-	-
*Holcus lanatus**	-	1	3	-	-	-	26	6	-	-	-	-
*Hypericum perforatum**	-	4	-	1	-	8	25	10	-	2	5	7
Hypericum sp.	-	1	1	-	-	-	-	-	-	-	-	-
Inula conyza	-	-	-	-	-	-	-	-	-	-	1	-
*Juncus tenuis**	-	-	1	-	-	-	14	-	-	-	-	-
*Plantago major**	-	-	-	-	-	-	4	-	-	1	1	7
Poa annua	-	2	-	2	-	-	1	-	-	-	-	-
Poa pratensis	-	-	-	-	1	-	-	1	-	-	-	-
Polygonum aviculare	-	-	-	-	4	-	23	-	8	-	-	-
Potentilla intermedia	-	-	-	-	-	3	3	4	-	-	-	-
*Potentilla norvegica**	-	12	-	1	5	9	7	8	3	-	29	-
Potentilla sp.	-	-	-	-	-	-	10	-	-	-	-	-
*Prunella vulgaris**	-	-	-	-	-	-	-	4	-	-	-	1
*Ranunculus repens**	-	-	-	-	-	-	-	2	-	-	-	-
Sagina procumbens	-	10	-	-	1	19	100	130	-	10	-	43
Senecio inaequidens	-	-	-	-	1	-	-	-	-	-	-	-
*Solidago gigantea**	-	1	26	1	-	-	3	-	-	-	-	-
Spergula arvensis	-	-	-	-	-	-	-	-	-	2	-	1
Spergularia rubra	-	-	-	-	2	-	-	-	-	-	-	-
Stellaria media	-	1	-	-	-	-	-	-	-	-	-	-
Poaceae spec.	-	-	-	-	-	-	-	-	-	-	-	3
Symphytum officinale	-	1		-	1	-	-	-	-	-	12	-
Taraxacum officinale agg.*	-	1	-	-	1	-	-	-	-	-	-	-
Tripleurospermun perforatum	-	1	-	-	-	-	1	-	-	-	-	-
*Veronica arvensis**	-	1	-	-	-	-	-	-	-	3	-	-
Veronica serpyllifolia	-	-	-	-	-	1	1	-	-	-	-	-
Vulpia myuros	-	-	-	-	-	-	-	-	-	2	2	-
Total diaspores and seedlings	-	38	66	102	179	42	427	189	19	31	157	105
Total taxa	-	13	8	7	7	6	26	17	3	11	13	14

Table A2. Diaspores in the diaspore bank of shrub site SR on industrial land (coal-mining spoil). *W* Results of seed washing method, *E* results of seed emergence method, *asterisks* indicate species which are common in the above-ground vegetation

Year of investigation	2000				2001				2003			
Date of collection	14 Jul		2 Oct		9 May		10 Sept		22 Jul		20 Sept	
Species/ method	W	E	W	E	W	E	W	E	W	E	W	E
*Acer pseudoplatanus**	-	-	-	-	-	-	-	-	-	-	1	-
Anagallis arvensis	-	-	-	-	-	-	-	-	-	-	4	1
Arenaria serpyllifolia	-	-	-	-	-	-		-	-	1	-	-
Artemisia vulgaris	-	-	1	-	-	-	-	-	-	-	1	1
*Betula pendula**	-	-	1091	-	726	-	953	-	214	13	627	134
Capsella bursa- pastoris	-	-	-	-	-	-	-	-	5	-	6	-
Carex sp.	-	-	-	-	1	-	-	-	-	-	-	-
Chenopodium polyspermum	-	-	1	-	-	-	-	-	-	-	-	-
Epilobium parviflorum	-	-	-	-	-	-	1	-	-	-	-	-
*Fragaria vesca**	-	-	91	1	62	1	24	1	-	-	-	-
Crepis capillaris	-	-	-	-	-	-	-	-	-	-	1	-
Hypericum perforatum	-	-	-	-	-	-	2	-	-	-	-	-
Lolium perenne	-	-	-	-	-	-	-	-	-	-	-	4
Medicago lupulina	-	-	-	-	-	-	-	-	30	-	58	-
Plantago major	-	-	-	-	-	-	-	-	-	-	5	-
*Poa annua**	-	-	-	1	-	-	-	-	-	1	-	-
Poaceae	-	-	-	-	-	-	-	-	3	-	-	-
Polygonum aviculare	-	-	6	-	-	-	-	-	-	-	-	-
Potentilla norvegica	-	-	4	-	-	-	-	-	-	-	-	-
Robinia pseudoacacia	-	-	-	-	2	1	2	-	-	-	-	-
*Rubus fruticosus agg.**	-	-	2	-	-	-	-	-	5	-	1	-
Rubus sp.	-	-	-	-	6	-	6	-	-	-	-	-
Sambucus nigra	-	-	-	-	-	-	5	-	-	-	-	-
Senecio inaequidens	-	-	1	-	-	-	-	-	-	-	-	-
*Solidago gigantea**	-	-	-	1	-	-	-	-	-	-	-	-
Total diaspores and seedlings	-	-	1197	3	797	2	993	1	257	15	704	140
Total taxa	-	-	8	3	5	2	7	1	5	3	9	4